Effects of Elevated Atmospheric CO_2 on Biomass Production and C Sequestration: Conventional and Conservation Cropping Systems

Stephen A. Prior[1], G. Brett Runion[1], H. Allen Torbert[1], Hugo H. Rogers[1] and D. Wayne Reeves[2]

USDA-ARS National Soil Dynamics Laboratory, 411 South Donahue Drive, Auburn, Alabama, 36832 USA
Email: sprior@acesag.auburn.edu
USDA-ARS J. Phil Campbell Sr. Natural Resource Conservation Center, Watkinsville, Georgia, 30622 USA

Abstract: Increasing atmospheric CO_2 concentration may impact production agriculture's role in sequestering carbon (C). This study was initiated (fall 1997) to compare the effects of elevated CO_2 on two cropping systems (conventional and conservation). The experiment was a split-plot design replicated three times with two cropping systems as main plots and two CO_2 levels (ambient and twice ambient) as subplots using open top field chambers on a Decatur silt loam (clayey, kaolinitic, thermic Rhodic Paleudults). The conventional system consisted of a grain sorghum [*Sorghum bicolor* (L.) Moench.] and soybean [*Glycine max* (L.) Merr.] rotation using conventional tillage practices and winter fallow. In the conservation system, sorghum and soybean were rotated and three cover crops (also rotated) were used [crimson clover (*Trifolium incarnatum* L.), sunn hemp (*Crotalaria juncea* L.), and wheat (*Triticum aestivum* L.)] using no-tillage practices. The conservation system had either cash or cover crops grown throughout the year with no fallow periods (in order of: clover, sorghum, sunn hemp, wheat, and soybean). Biomass responses over two complete 2-year cropping cycles (total of 4 years) and the effect of these two contrasting management systems on C sequestration were evaluated. In the conservation system, cover crop residue production (clover, sunn hemp, and wheat) was increased by high CO_2, but CO_2 effects on weed residue were variable in the conventional system. Elevated CO_2 had a greater effect on increasing soybean residue compared to sorghum. Grain yield increases due to added CO_2 were greater for soybean followed by wheat and sorghum. Differences in sorghum and soybean residue production within the different management systems were small and variable. Cumulative non-yield residue inputs (both 2 yr cycles) were increased by elevated CO_2 and conservation management. Greater inputs resulted in a substantial increase in soil C concentration at the 0-5 cm depth increment in the conservation system under CO_2-enriched conditions. Conservation management increased soil C concentration at lower depths (5-10 and 15-30 cm) and CO_2-induced increases also occurred at the 5-10 cm depth (similar trend at15-30 cm) in both management systems. Results suggest that with conservation management in a high CO_2 environment, greater amounts of crop residue could increase soil C storage as well as increase ground cover, improve water infiltration and soil water retention, and reduce erosion.

Key words: C sequestration, cover crops, conservation tillage, grain crops, soil carbon

INTRODUCTION

The global atmosphere is changing as evidenced by the well documented rise in atmospheric CO_2 concentration, which is expected to continue (Keeling and Whorf, 1994). This global rise can be attributed to fossil fuel burning, land use change associated with population growth, and industrial expansion (Houghton *et al.*, 1992). Since CO_2 is a primary input to crop growth, there is interest in how this rise in CO_2 will impact highly managed agricultural systems.

Over the last decade, numerous studies have demonstrated that elevated atmospheric CO_2 can result in greater biomass production (Amthor, 1995). The effect of elevated CO_2 on the amount of crop residues can influence soil C dynamics in agroecosystems (Rogers *et al.*, 1999; Torbert *et al.*, 2000). Furthermore, soil C storage can be altered by management practices (e.g., fertility practices, tillage methods, and cropping systems including cover crops) (Kern and Johnson, 1993; Potter *et al.*, 1998).

There is, however, a lack of information on how elevated CO_2 will interact with management practices, especially the newer ones being used in conservation systems. Such information is needed to accurately predict shifts in biomass productivity that will impact soil C storage patterns under different residue management schemes. The capability of soil to act as a sink for C storage in CO_2-enriched agroecosystems is a highly relevant issue since the potential for C storage in agricultural soils is of special interest in the current climate change policy debate.

In the current study, crops were grown in a large outdoor soil bin under two different atmospheric CO_2 environments (ambient and twice ambient CO_2 levels) and management conditions (conventional tillage and conservation tillage). The objective was to investigate the effects of increased CO_2 level on biomass production and soil C storage patterns for these different management systems.

MATERIALS AND METHODS

This study was initiated in the fall of 1997 using an outdoor soil bin (7m x 76 m) at the USDA-ARS National Soil Dynamics Laboratory in Auburn, Alabama, USA (Batchelor, 1984). A split-plot design replicated three times was used with two cropping systems (conventional and conservation) as main plots and two CO_2 levels (365 and 720 :ll^{-1}) as subplots using open top field chambers (Rogers *et al.*, 1983) on a Decatur silt loam (clayey, kaolinitic, thermic Rhodic Paleudults).

This report covers two of three, two-year cycles in a ongoing 6-year study comparing two management systems. In the conventional system, grain sorghum and soybean were rotated each year with spring tillage after winter fallow. In the conservation system, grain sorghum and soybean were also rotated, but with three winter cover crops (crimson clover, sunn hemp, and wheat) which were also rotated; all were grown using "no-tillage" practices. The wheat served as cover as well as being harvested for grain. Cover crops were broadcast planted while row crop seeds were planted on 0.38 m row spacings. Extension recommendations were used in managing the crops; fertilizer rates were based on standard soil tests.

At final harvest, all plants were removed and total fresh weights recorded. A subsample of the non-yield material (residue) was taken and its fresh weight recorded; the subsample was dried (55 ^{o}C) and total residue was determined by calculation using the fresh weight to dry weight ratio for each plot. The remaining residue material was returned to each plot. For grain crops (sorghum, soybean, and wheat), fresh weights and grain moisture of threshed grain were determined; total yields were determined following correction for moisture. In the conventional system (following the fallow period), aboveground weed dry weight was measured as described above and residue was returned to plots prior to tillage.

Soil samples were collected (4 cores per plot) at the end of the second cropping cycle (4th year) using procedures as described by Prior and Rogers (1992). Cores (3.8 cm diameter) were partitioned into 0-5, 5-10, 10-15, 15-30, and 30-40 cm depth increments, sieved (2 mm), and oven dried (55 ^{o}C). Subsamples were ground to pass a 0.15 mm sieve and analysed for total C and total N on a LECO CN 2000 (LECO Corp., Saint Joseph, MI). Statistical analyses were performed using mixed model procedures (Proc Mixed) of the Statistical Analysis System (Littell *et al.* 1996). A significance level of $P < 0.10$ was established *a priori*.

RESULTS

As expected, positive biomass responses to CO_2 enrichment were often noted in the first cropping cycle (Figure 1). This cycle began with a evaluation of clover (conservation system) and weed (conventional system) production prior to sorghum planting. A significant CO_2 x management interaction was noted; elevated CO_2 increased clover residue production by 23%, but had no detectable impact on the weeds. The following sorghum crop was unaffected by management; however, the main effect of CO_2 was significant and residue production was increased by ~14%. Sorghum grain yield was not affected by CO_2 level. Yield was slightly increased (6%) due to conservation management. The following legume cover crop, sunn hemp, was used to fill a two month gap which is usually left fallow until wheat planting. Elevated CO_2 resulted in a 32% increase in sunn hemp residue in the conservation system, but there was no weed production in the conventional system due to previous herbicide application. At the next sampling, significant main effects of CO_2 and management indicated that high CO_2 increased residue production and that the conservation system produce more residue (wheat) compared to the conventional system (weeds). Wheat grain yield was increased (32%) by high CO_2. For soybean, significant main effects of CO_2 and management were also noted. Elevated CO_2 increased soybean residue (49%) and grain production (40%), but conservation management only resulted in a small increase in residue (4%) and grain (6%).

In the second cropping cycle (Figure 2), a significant CO_2 x management interaction was also noted; elevated CO_2 increased production of clover residue by 22%, but had no impact on weeds. For sorghum, the main effects of CO_2 and management were significant for residue and grain production. Elevated CO_2 increased sorghum residue (24%) and grain (22%), while conservation management resulted in ~13% increase in these variables. Elevated CO_2 resulted in a 61% increase in sunn hemp residue in the conservation system, but there was no weed production in the conventional system due to previous herbicide application. As observed in the first cycle for wheat, significant main effects of CO_2 and management indicated that high CO_2 increased residue production and that the conservation system produced more residue (wheat) compared to the conventional system (weeds). For soybean, significant main effects of CO_2 and management were noted for residue production. Elevated CO_2 increased soybean residue by 49%. Conservation management resulted in a small (9%) decrease in residue. For soybean grain, only the main effect of CO_2 was significant; elevated CO_2 increased grain yield by 52%.

Cumulative non-yield residue inputs to the soil were increased by elevated CO_2 and the use of conservation management (Figs. 1F and 2F). Across both cropping cycles, CO_2 level increased cumulative residue production by ~30% regardless of management practice. Use of conservation practices led to an increase in cumulative residue production of ~90% (both 2 yr cycles). Increases in cumulative inputs resulted in changes in soil C and N concentration (Figure 3); changes in soil N concentration followed a similar pattern as observed with soil C concentration over the depth increments evaluated. The most notable difference attributable to management practice was observed at the top depth increment (0-5 cm). Clearly, increased inputs combined with lack of tillage (conservation management) resulted in a higher soil C concentration. A significant CO_2 x management interaction was noted for the surface increment, 0-5 cm. In this case, a dramatic increase in soil C concentration (44%) occurred in the conservation treatment under CO_2 enrichment. The mean for the elevated CO_2-conventional treatment was higher, but not significant. The main effects of CO_2 and management were significant for other depth increments. Conservation management increased soil C concentration at lower depths (5-10 and 15-30 cm) and CO_2-induced increases also occurred at the 5-10 cm depth (similar trend at 15-30 cm). Results suggest that in a high CO_2 environment, crop residue could increase soil C storage. However, the potential to store soil C will be greater in conservation systems compared to conventional.

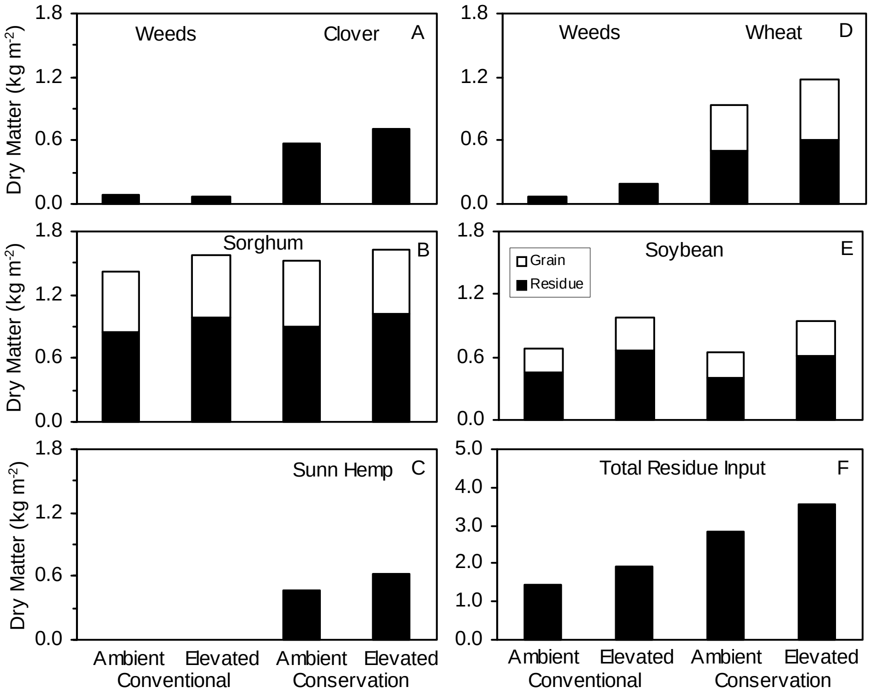

Figure 1. Biomass production (residue and/or grain) for weeds/clover (A), sorghum (B), sunn hemp (C), weeds/wheat (D), soybean (E), and total residue inputs (F) under ambient and elevated CO_2 conditions and two management systems (conventional and conservation) for the first 2-year cropping cycle are shown.

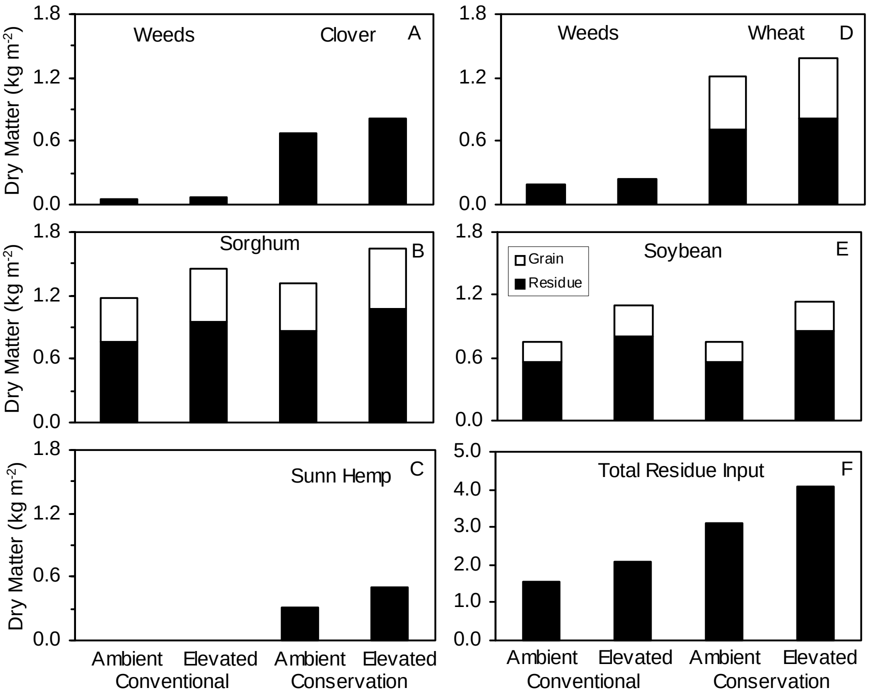

Figure 2. Biomass production (residue and/or grain) for weeds/clover (A), sorghum (B), sunn hemp (C), weeds/wheat (D), soybean (E), and total residue inputs (F) under ambient and elevated CO_2 conditions and two management systems (conventional and conservation) for the second 2-year cropping cycle are shown.

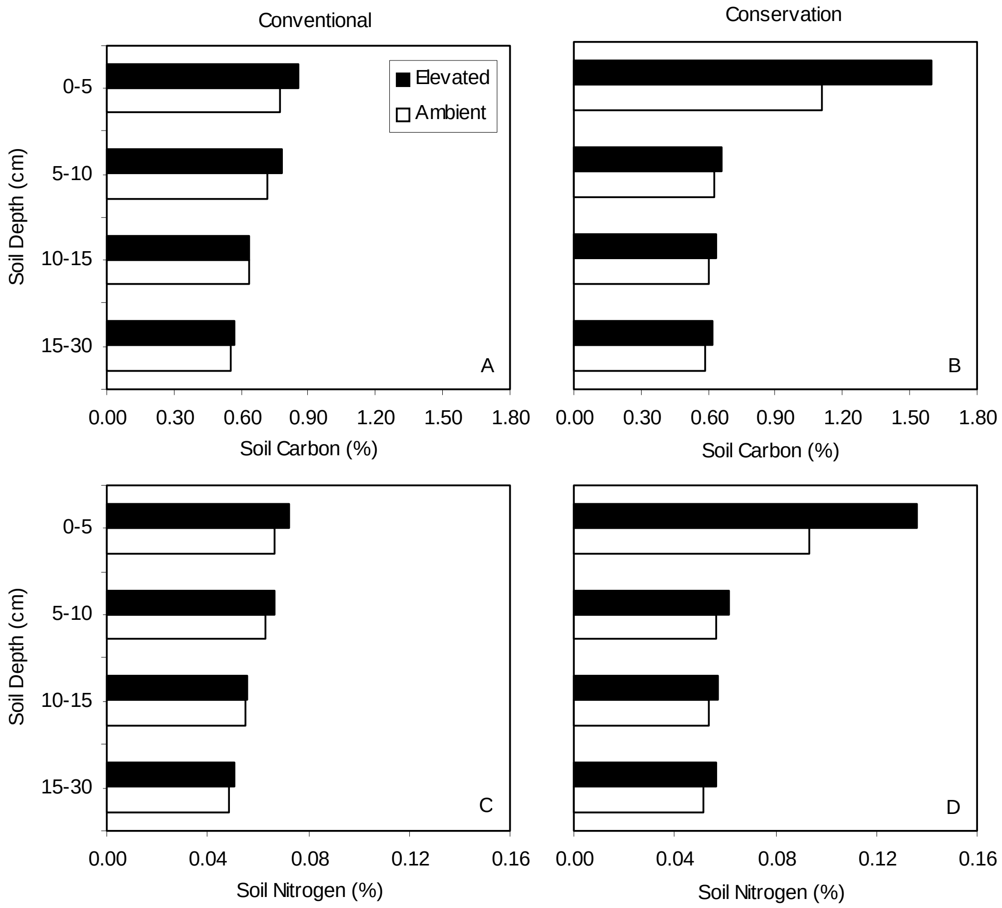

Figure 3. Soil carbon (A, B) and nitrogen (C, D) concentration at various depth increments as affected by atmospheric CO_2 level (ambient and elevated) and management system [conventional (A, C) and conservation (B, D)] after two complete cropping cycles (4 years).

CONCLUSIONS

Aboveground biomass production was often stimulated by elevated atmospheric CO_2 and conservation management. Increased amounts of cover crop residue production can be expected under CO_2 enrichment in conservation systems. But, the variable response of weeds to CO_2 in the conventional system indicates that further work is required to clarify management implications. Rising CO_2 levels can be expected to increase soybean residue more than that of sorghum. Likewise, yield will likely be increased (due to high CO_2) for soybean followed by wheat and sorghum. Differences in residue production (for both sorghum and soybean) between management systems may not be great under elevated CO_2. Cumulative residue production is likely to be increased by CO_2 enrichment and conservation management. Larger residue inputs were associated with increased soil C and vertical stratification of C within the soil profile. These results indicate that in a future elevated CO_2 world, agroecosystems could potentially store more C, especially with conservation management. Furthermore, results suggest that with conservation management in a high CO_2 environment, greater amounts of crop residue will increase ground cover (thereby improving water infiltration and soil water retention, and reducing soil erosion). Future efforts will assess CO_2 effects on other belowground processes in these management systems; soil C content, root dynamics (minirhizotrons), distribution of nutrients in the soil profile, soil water holding capacity, and soil physical properties (e.g. water stable aggregates, hydraulic conductivity, and bulk density) will be considered.

Acknowledgements

The authors thank B.G. Dorman, J.W. Carrington, T.K. Dorman, E.B. Schwab, and J.A. Walker for technical assistance. This research was supported by the Biological and Environmental Research Program (BER), U.S. Department of Energy, Interagency Agreement No. DE-AI02-95ER62088.

References

Amthor, J.S. Terrestrial higher-plant response to increasing atmospheric [CO_2] in relation to the global carbon cycle, *Global Change Biology* **1**, 243-274, 1995.

Batchelor, J.A. Jr. *Properties of Bin Soils at the National Tillage Machinery Laboratory, Publ. 218*, USDA-ARS National Soil Dynamics Laboratory, Auburn, Alabama, 1984.

Houghton, J.T., B.A. Callander and S.K. Varney. *Climate Change 1992: The Supplementary Report to the IPCC Scientific Assessment*, Cambridge University Press, Cambridge, 1992.

Keeling, C.D. and T.P. Whorf. Atmospheric CO_2 records from the sites in the SIO air sampling network, In T.A. Boden, D.P. Kaiser, R.J. Sepanski and F.W. Stoss (Eds), *Trends '93: A Compendium of Data on Global Change, ORNL/CDIAC-65*,The Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tennessee, pp. 16-26, 1994.

Kern, J.S. and M.G. Johnson. Conservation tillage impacts on national soil and atmospheric carbon levels, *Soil Science Society of America Journal* **57**, 200-210, 1993.

Littell, R.C., G.A. Milliken, W.W. Stroup and R.D. Wolfinger. *SAS System for Mixed Models*. SAS Institute, Inc., Cary, North Carolina, 1996.

Potter, K.N., H.A. Torbert, O.R. Jones, J.E. Matocha, J.E. Jr. Morrison and P.W. Unger. Distribution and amount of soil organic carbon in long-term management systems in Texas. *Soil Tillage Research* **47**, 309-321, 1998.

Prior, S.A. and H.H. Rogers. A portable soil coring system that minimises plot disturbance, *Agronomy Journal* **84**, 1073-1076, 1992.

Rogers, H.H., W.W. Heck and A.S. Heagle. A field technique for the study of plant responses to elevated carbon dioxide concentrations, *Air Pollution Control Association Journal* **33**, 42-44, 1983.

Rogers, H.H., G.B. Runion, S.A. Prior and H.A. Torbert. Response of plants to elevated atmospheric CO_2: Root growth, mineral nutrition, and soil carbon, In Y. Luo and H.A. Mooney (Eds), *Carbon Dioxide and Environmental Stress*, Academic Press, San Diego, California, pp. 215-244, 1999.

Torbert, H.A., S.A. Prior, H.H. Rogers and C.W. Wood. Elevated atmospheric CO_2 effects on agro-ecosystems: Residue decomposition processes and soil C storage, *Plant and Soil* **224**, 59-73, 2000.